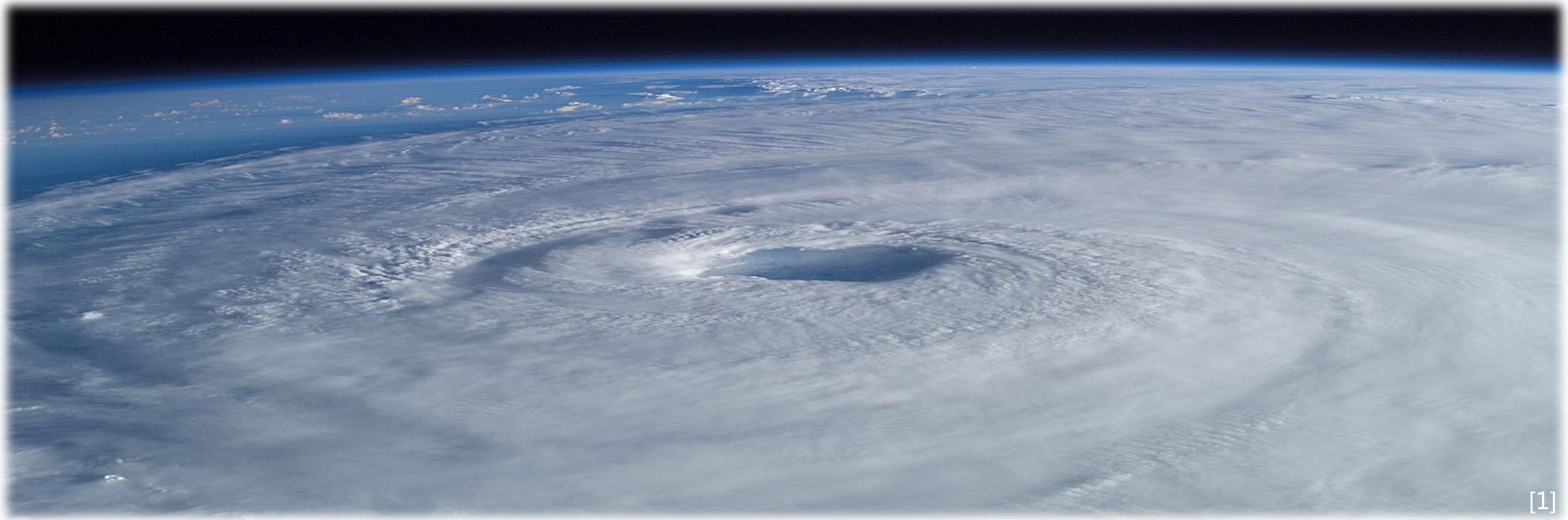

Integrated Kinetic Energy of Tropical Cyclones in PRIMAVERA simulations

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Motivation

- Tropical cyclones (TCs) are the costliest natural disasters (e.g. US hurricane season 2017 when Hurricanes Harvey, Irma & Maria accumulated ≈ 250 billion $US loss) [2-5]
- Effect of climate change on TCs still relatively unknown (indications for increase in precipitation & lifetime max. intensity, decrease in global frequency) [6]
- Standard measures of TC intensity do not correlate well with damages as they do not consider storm size, which has been shown to be beneficial to damage estimates [7-11]
- Studies show that refined horizontal resolutions lead to more realistic representations of TCs in climate models [12]

➢ This is what we are doing in this study in order to provide an estimate of the changes between present & future TC potential damages

➢ Since CMIP6 HighResMIP simulations have resolutions that allow a more realistic representation of TCs, the PRIMAVERA project now provides a good opportunity to look at the wind fields of TCs between the present & future at different resolutions

Outline

1. Methodology
   - Experiment & model
   - BSC cyclone tracker
   - Integrated kinetic energy (IKE)
2. Results
   - Storm tracks & numbers
   - Effect of resolution on IKE probability
   - Cyclone structure
   - IKE in a future climate
3. Summary & conclusions
4. Questions

Methodology: Experiment & model

- HighResMIP: Atmosphere-only run for tier 1 & tier 3
  - Historic run: 1950 – 2014 ("present")
  - Future projection: 2015 – 2050 ("future")

- CNRM: Use as a test and expand to coupled version & other models
  - Fully coupled ocean-atmosphere GCM
  - Components other than atmosphere prescribed by HighResMIP protocol
  - Experiments performed at 2 different horizontal resolutions

Resolution	Truncation	Analysis grid	Vertical levels
Low ("LR")	Tl127	1.4° x 1.4°	91
High ("HR")	Tl359	0.5° x 0.5°	91

[13]

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Methodology: BSC cyclone tracker

- Modified version of the GFDL Vortex Tracker V3.5b ("tracker") in ESMValTool

- Uses mean sea level pressure (MSLP) to provide estimates of location, intensity and structure of potential storm candidates at each 6-hour time step

- Input variables:

mandatory
- Mean sea level pressure
- Horizontal wind speed components at 850 & 700 hPa (or at 500 hPa)

} evaluate storm candidates

optional
- Surface horizontal wind speed components
- Geopotential height at 850 & 700 hPa

} correct storm centre

- 400 hPa temperature field → distinguish from extra-tropical cyclones

Methodology: Integrated kinetic energy (IKE)

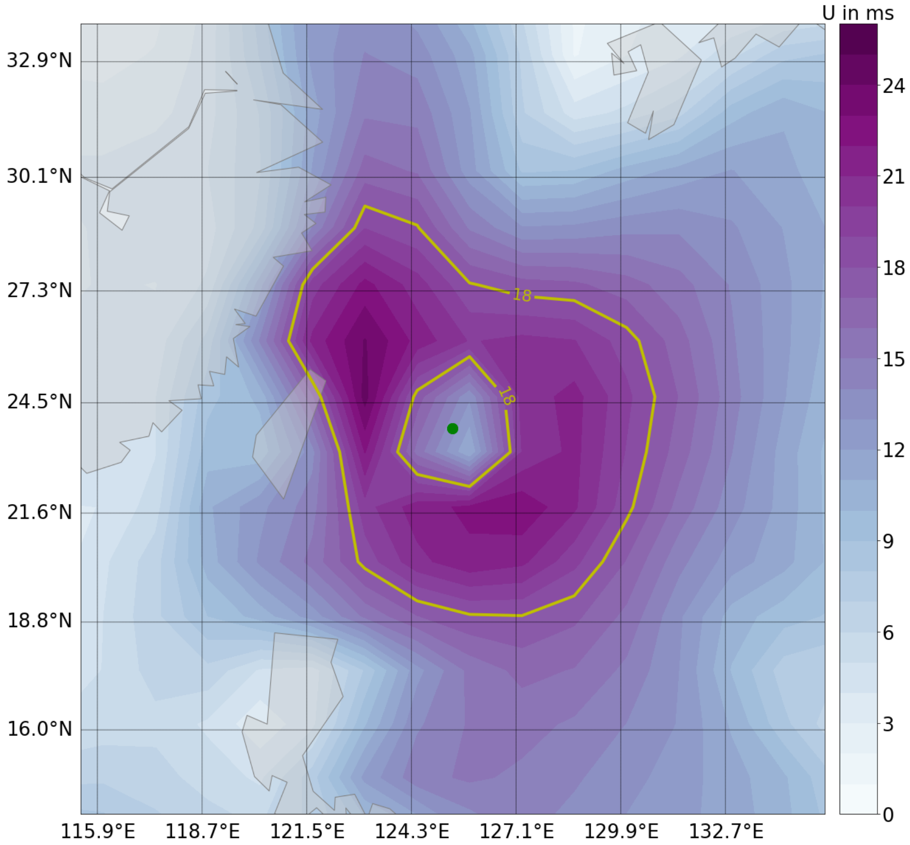
- Integrated measure to assess the level of energy of a storm at each time step
- Unlike ACE or PDI, IKE does not only consider maximum wind speed, but also lower wind speeds by summing up the contribution of the entire wind field

$$\mathrm{ACE} = 10^{-4} \sum v_{\max}^2$$ [14]

$$\mathrm{PDI} \equiv \int_0^{\tau} V_{\max}^3 \, dt$$ [6]

$$\mathrm{IKE} = \int_V \frac{1}{2} \rho U^2 dV$$ [7]

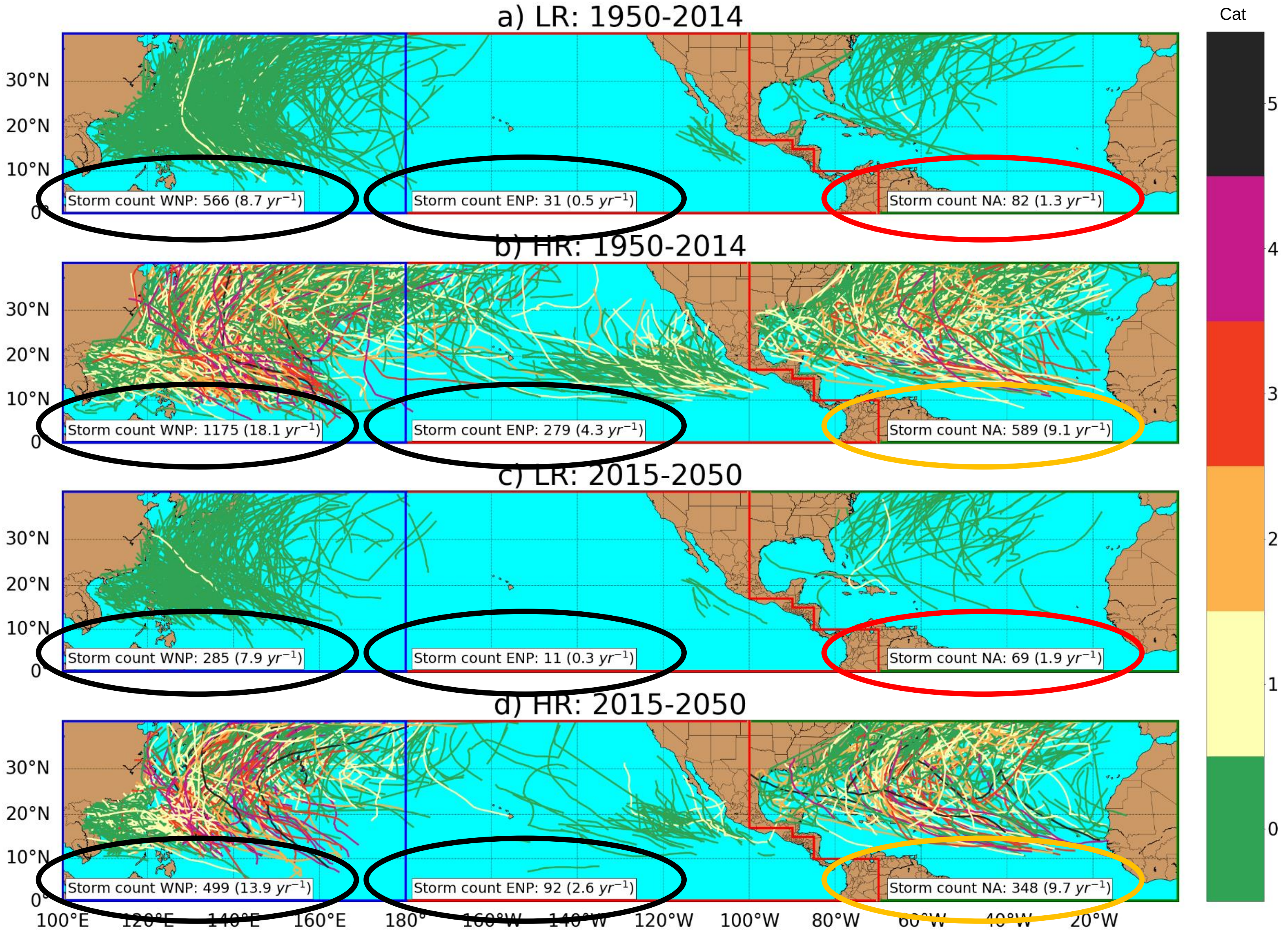
- Tracking criteria:
  - Wind speed ≥ 18 ms^{-1} for at least 24 hrs
  - Northern hemisphere
  - Storm season: June - November



Wind speed field of an example TC in CNRM. 18 ms^{-1} isoline and storm centre (green dot) are depicted.

Results: Storm tracks & numbers

- North Eastern Pacific under-represented
- More storms resolved in HR
- LR significant problems to produce TCs > Cat 1
  - ➢ Much better in HR
- Decrease in overall frequency from present to future
- Regional differences:
  - ➢ Decrease in Pacific
  - ➢ Increase in Atlantic



Storm tracks as recognised by the tracker and categorised after their lifetime max. intensity.

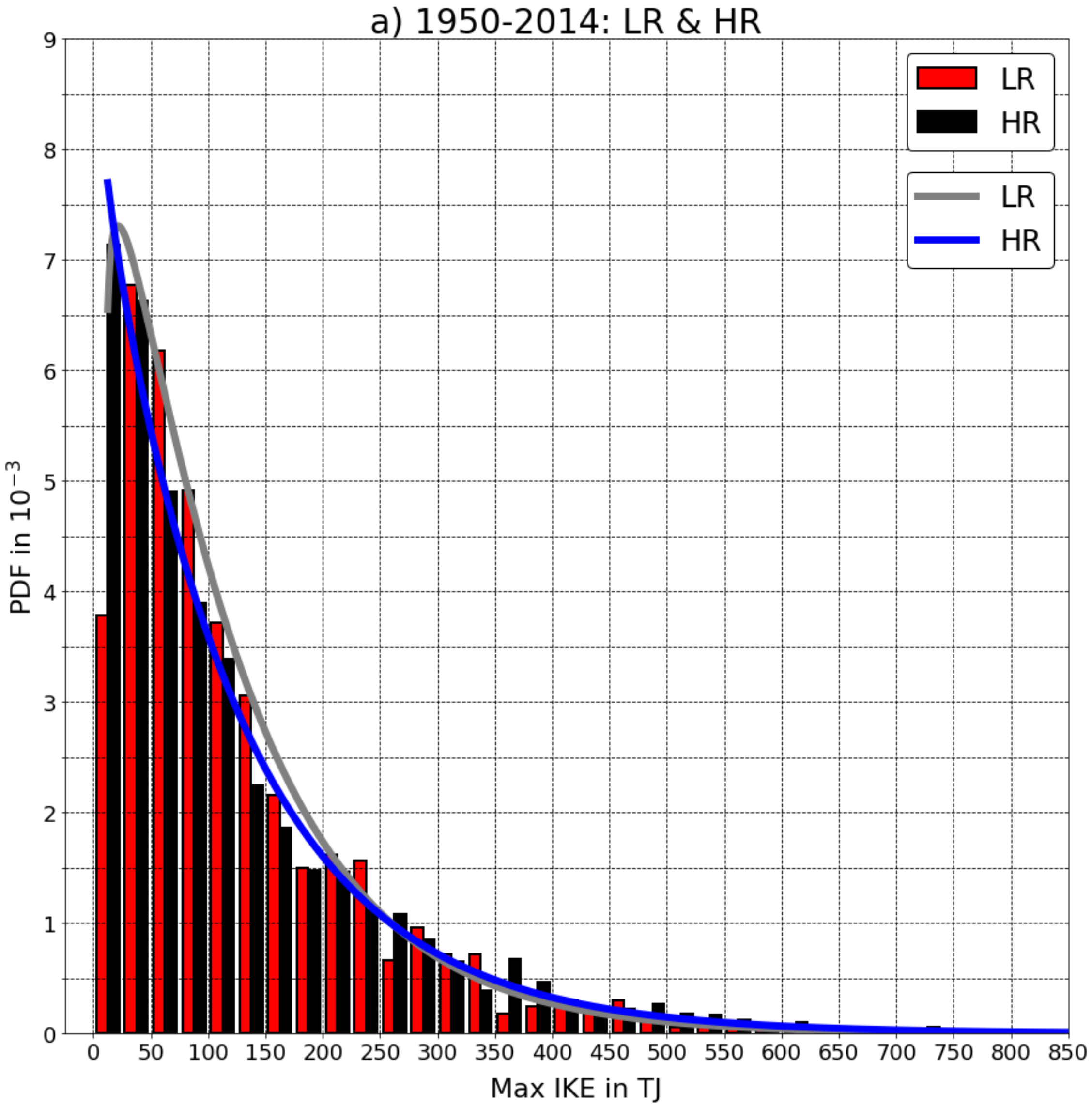
PRIMAVERA Results: Effect of resolution on IKE probability

- HR: More intense storms

➢ Is there a change in probability towards more energetic storms?

- PDFs, fitted Gamma distribution & Kolmogorov-Smirnov test:

  - ➢ Significant (5 %) difference between IKE in LR & HR
  - ➢ But: Difference in high energetic storms not pronounced
  - ➢ Effect of intensity compensated by smaller storm sizes?



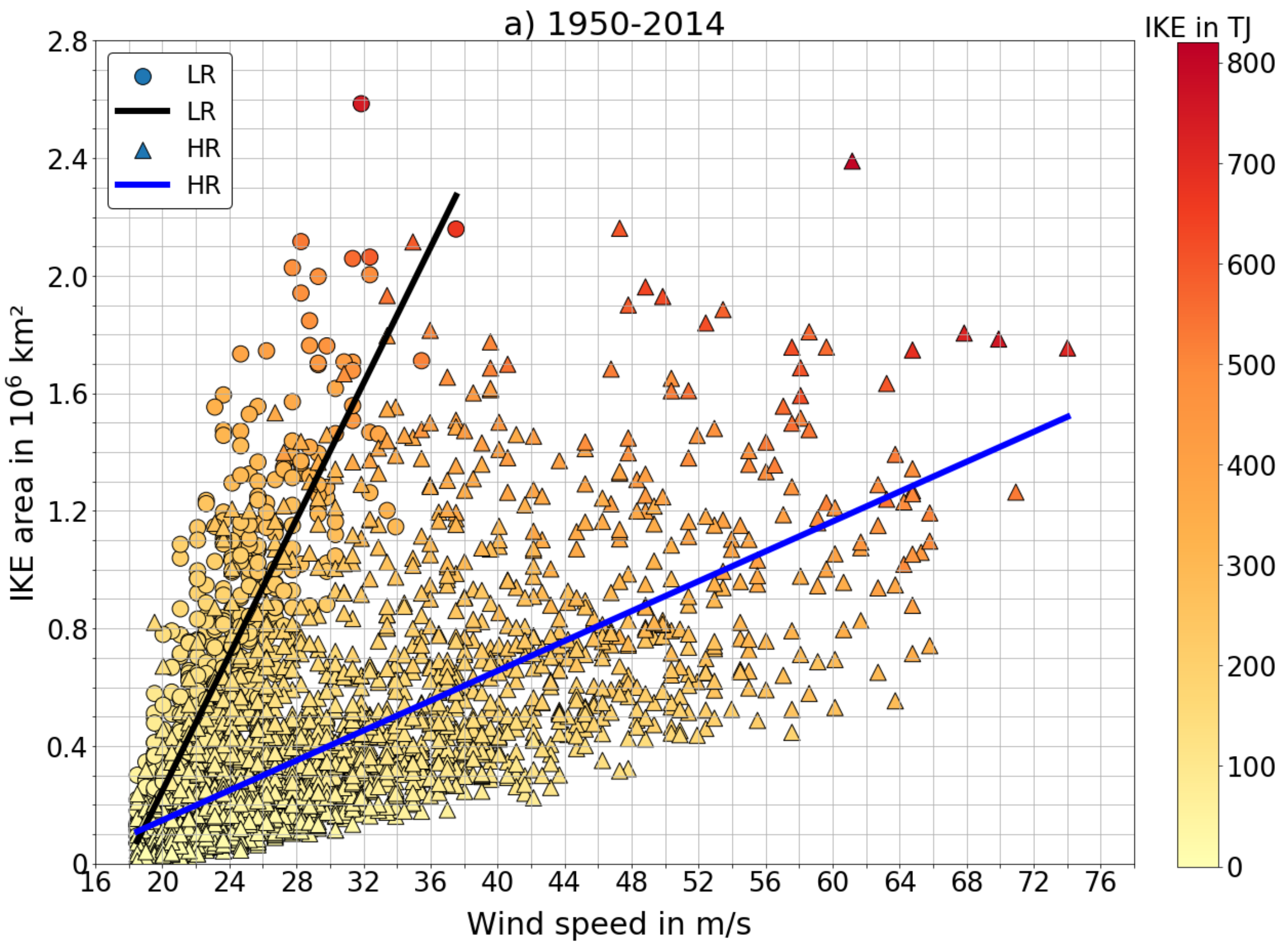
PDF for storms in the entire northern hemisphere, sorted after their lifetime max. IKE from 1950-2014. Gamma distribution is fitted.

Results: Cyclone structure

- Why is the IKE between the two resolutions similar?

- Regressions suggest that storms in HR are more intense & smaller at similar IKE

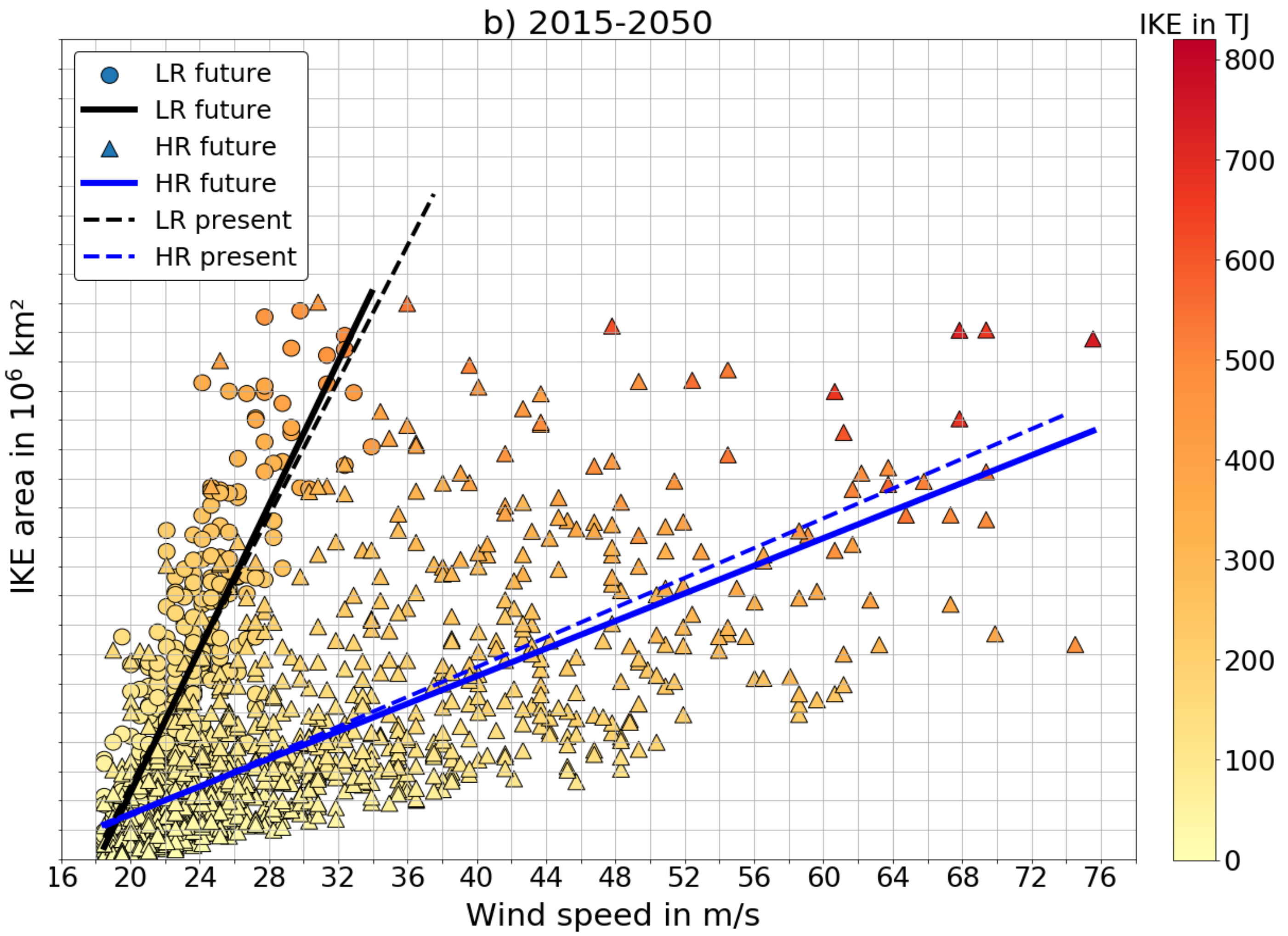
- Increasing effect of wind speed on IKE is weakened by decreasing effect of shrinking storm size



Scatter plot (IKE area against max. wind speed at time of max. lifetime IKE) for all storms in the entire northern hemisphere from 1950-2014. Colour coded with IKE value. Regression lines for LR & HR are added.

Results: IKE in a future climate

- Difference between regressions for future period small



Scatter plot (IKE area against max. wind speed at time of max. lifetime IKE) for all storms in the entire northern hemisphere from 2015-2050. Colour coded with IKE value. Regression lines for LR & HR are added. (also for 1950-2014)

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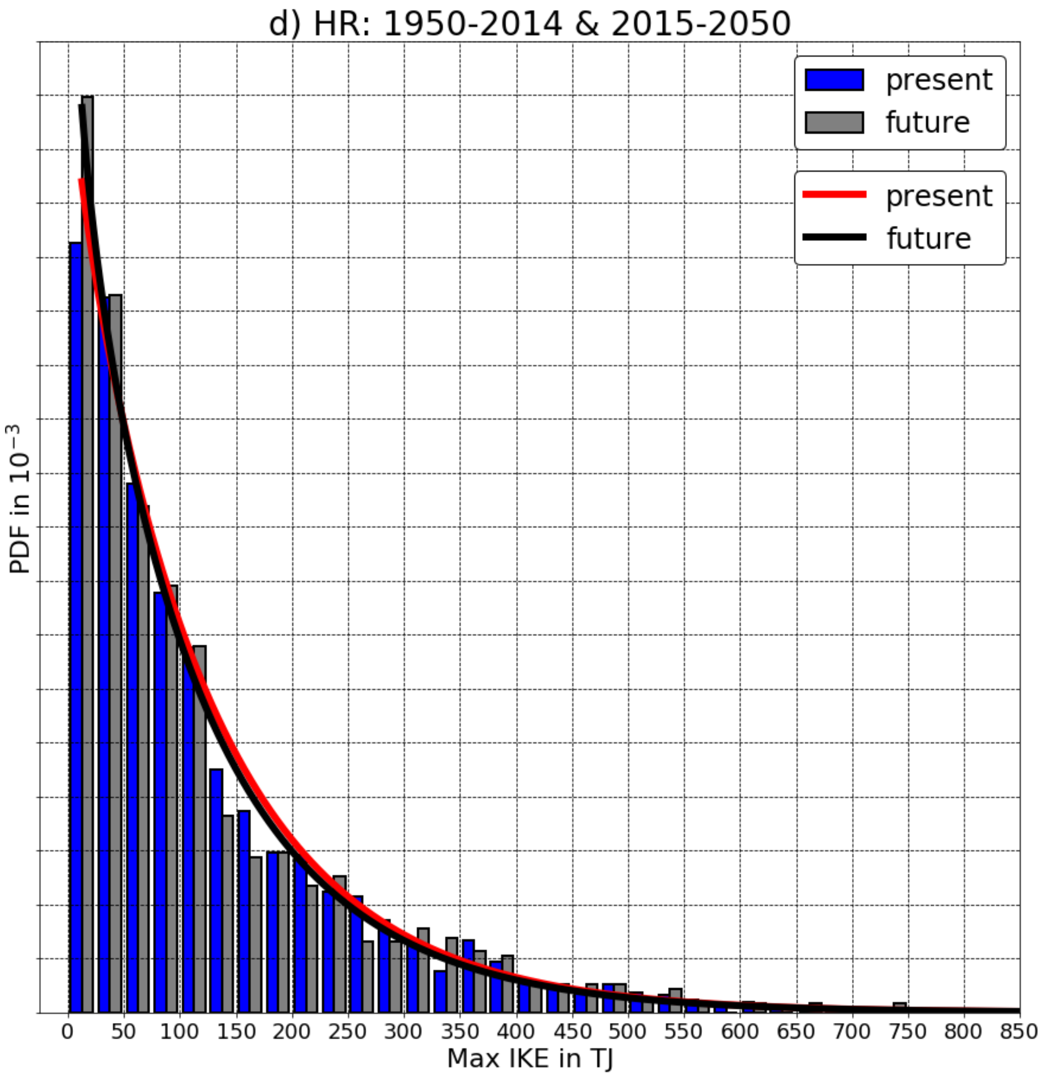
Results: IKE in a future climate

- Difference between regressions for future period small
- No significant change in IKE between present & future periods

➢ Impact of climate change on TC intensity and size relatively small on global scale

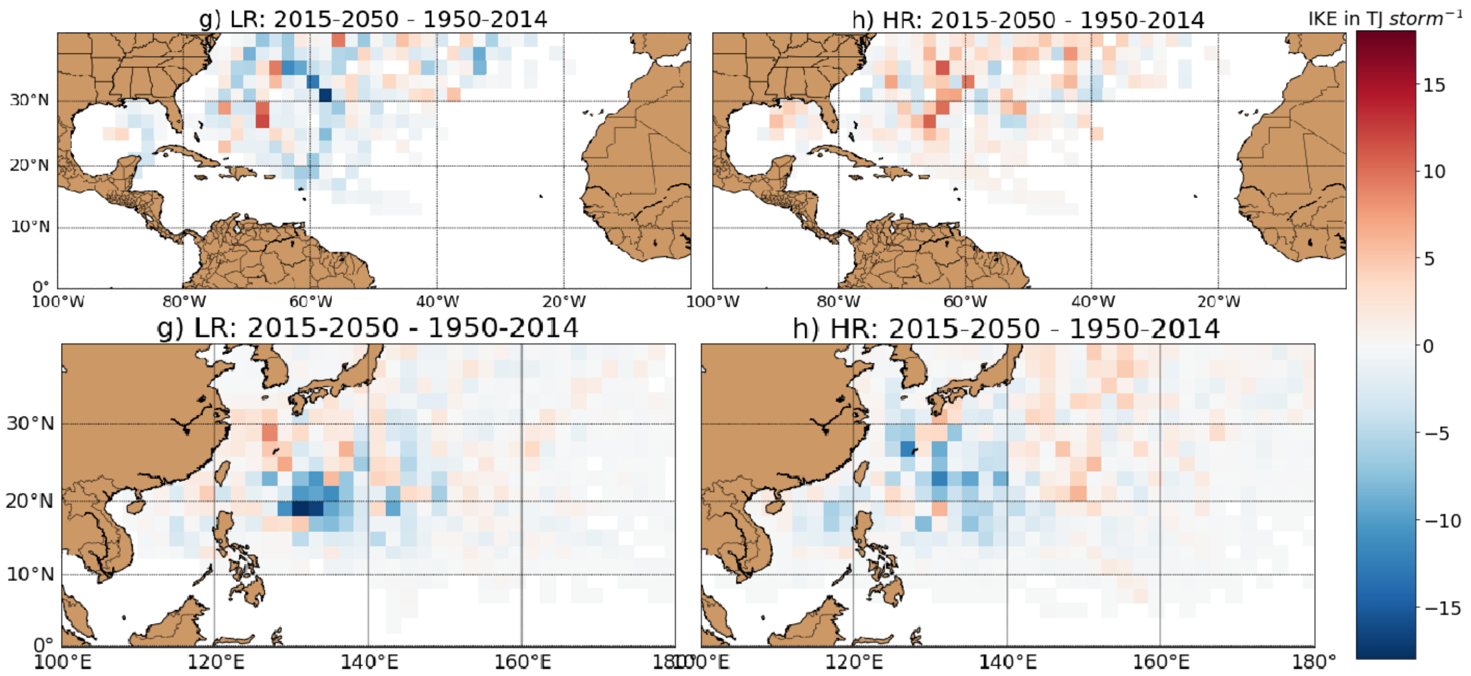
➢ Basin scale?



PDF for storms in the entire northern hemisphere, sorted after their lifetime max. IKE for HR. Gamma distribution is fitted.

Results: IKE in a future climate

- Different signals between LR & HR in Atlantic
  - ➢ Uncertain response
- Negative signal in both resolutions in Pacific
  - ➢ Storms in Pacific could get less energetic
- Similar results for coupled experiment & other models?



Difference in IKE per storm (storm number per respective basin) between future and present period in 2° x 2° grid boxes in the Atlantic (top) and the Western North Pacific (bottom). Results for both basins are shown for LR (left) and HR (right).

Summary & conclusions

- Climatology:
  - Refinement in resolution increases number & intensity of generated storms
  - Overall decrease in frequency of storms in future (difference in individual basins)
- Cyclone structure:
  - HR: Storms get more intense and smaller at similar IKE
  - Resolution plays a major role in representing these features
- IKE probability:
  - HR: Increasing effect of wind speed outweighs decreasing effect of shrinking area
  - No significant change in global IKE content between future & present climate
  - Differences between & within the individual basins

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Questions?

References

- [1] https://upload.wikimedia.org/wikipedia/commons/thumb/0/04/Hurricane_Isabel_from_ISS.jpg/1024px-Hurricane_Isabel_from_ISS.jpg
- [2] Munich Re: Löw, P. (08.01.2019). The natural disasters of 2018 in figures. https://www.munichre.com/topics-online/en/climate-change-and-natural-disasters/naturaldisasters/the-natural-disasters-of-2018-in-figures.html.
- [3] Emanuel, Kerry. "Increasing destructiveness of tropical cyclones over the past 30 years." Nature 436.7051 (2005): 686-688.[3] Bevere L, Seiler T, Zimmerli P, Feyen H and H 2013 Natural
- [4] Catastrophes and Man-Made Disasters in 2012: A Year of Extreme Weather Events in the US (Zurich, Switzerland: SwissReinsur) p 40
- [5] Costliest U.S. tropical cyclones tables update (PDF) (Report). United States National Hurricane Center. January 12, 2018. Archived (PDF) from the original on January 26, 2018. Retrieved January 12, 2018.
- [6] Knutson, Thomas, et al. "Tropical cyclones and climate change assessment: Part II. Projected response to anthropogenic warming." Bulletin of the American Meteorological Society 2019 (2019).
- [7] Mahendran, M. "Cyclone intensity categories." Weather and forecasting 13.3 (1998): 878-883.
- [8] Kantha, Lakshmi. "Time to replace the Saffir-Simpson hurricane scale?." Eos, Transactions American Geophysical Union 87.1 (2006): 3-6.
- [9] Powell, Mark D., and Timothy A. Reinhold. "Tropical cyclone destructive potential by integrated kinetic energy." Bulletin of the American Meteorological Society 88.4 (2007): 513-526.
- [10] Yu, Jia-Yuh, and Ping-Gin Chiu. "Contrasting Various Metrics for Measuring Tropical Cyclone Activity." Terrestrial, Atmospheric & Oceanic Sciences 23.3 (2012).
- [11] Zhai, Alice R., and Jonathan H. Jiang. "Dependence of US hurricane economic loss on maximum wind speed and storm size." Environmental Research Letters 9.6 (2014): 064019.
- [12] Camargo, Suzana J., and Allison A. Wing. "Tropical cyclones in climate models." Wiley Interdisciplinary Reviews: Climate Change 7.2 (2016): 211-237.
- [13] Voldoire, A., et al. "Evaluation of CMIP6 DECK Experiments With CNRM-CM6-1." Journal of Advances in Modeling Earth Systems 11.7 (2019): 2177-2213.
- [14] Bell, Gerald D., et al. "Climate assessment for 1999." Bulletin of the American Meteorological Society 81.6 (2000): S1-S50.